Operating Manual

CarboProbe™ CP

Simple potter's probe

CarboProbe™ DS

Gas-tight oxygen probe

CarboProbe™ HT

Industrial oxygen probe

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1 Operational principles

The principle of operating an oxygen probe is dependent on two electrodes making contact with a platinum coated zirconium element at the tip of the sensor; one side is called the outer electrode and the other one the inner electrode.

The platinum wire is one conductor for the oxygen probe signal. Platinum has an excellent resistance to corrosion and oxidation at high temperature, this is why it is used.

The purpose of the ECONOX *CarboProbe™ CP, DS* and *HT* oxygen probes is to measure the oxygen content at high temperature (from 600°C to 1700°C).

1.1 General information

ECONOX uses the **C3M* ZrO_2** electrolyte made of ZrO_2 (zirconium oxide) for its oxygen sensors:

Fig 1: C3M ZrO_2 sensor

This ZrO_2 electrolyte is made of zirconium oxide (ZrO_2). When it is placed at working temperature and separate two gaseous areas with differing partial oxygen pressure (pO_2), its behavior is like an electrochemical battery by transferring oxygen ions.

At the terminals of both electrodes on the **C3M ZrO_2** electrolyte, the value of the voltage delivered is linked to the absolute temperature and the difference in partial oxygen pressures, according to the Nernst equation.

* The C3M sensor is an updated version of the C-700 sensor

1.2 Functional principle

The functional principle of a *CarboProbe™* is based upon the comparison of the two oxygen partial pressures in two separate gaseous mediums. The zirconium oxide which represents the measuring element has faults in its crystal structure, i.e. some of the sites which could be occupied by oxygen ions are free. At a temperature above 600°C the oxygen ions start to migrate, which is a typical feature of this ceramic material. This results in the measuring element becoming conductive. The voltage generated represents a relation between the relative difference of the oxygen concentrations and the ZrO_2 cell temperature.

In order to compare the partial pressure, the oxygen probe must be supplied with a gas of a known content of oxygen (ambient air: $\%O_2$ = 20.9 %). **This is what we call reference air**. Moreover, some of the Econox *CarboProbe™* are equipped with a thermocouple allowing measurement of the actual treatment temperature.

The measuring element of a *CarboProbe™* has a limited lifetime. Its surface layer changes depending on the impurities (soot or dust residues) which are found in the kiln/furnace atmosphere. Therefore, the measuring element should be replaced when its impedance exceeds the tolerances admitted.

2 Packaging

The Econox *CarboProbe™*, although a robust unit, must be unpacked and handled with care. Each probe is dispatched in a secure package.

This package should be kept in a secure place at all times, should the need arise to return the probe to Econox. Returning a probe in packaging other than the original may affect warranty conditions.

The package consists of an outer box and an inner layer of polyurethane which houses the carbon probe.

Each pack includes the probe together with the operating manual, warranty card, test certificate of the *CarboProbe™* and an access card to the Econox Online Services (www.econox.com/ecos).

3 Application

Oxygen probes can be used in a vast range of industries. CarboProbe™ CP, DS and HT **cannot be used** in carburizing mixtures. If you are operating a heat treatment furnace and measuring the %C, please consider using our CarboProbe™ ZI or ZS suitable for heat treatment*.

CarboProbe™ CP, DS and HT are mostly used for the following applications:

- Control of glaze color and firing ceramics
- Control of air supply in industrial incinerators
- Measurement of fuel/air ratios in combustion
- Fuel combustion efficiency control
- Furnace gas analysis
- Waste management systems
- Potters' kilns
- Annealing furnaces
- Flue gas analysis
- O_2 levels at high temperatures
- CO_2 harsh environments
- Technical ceramic kiln systems
- Industrial applications
- Universities and laboratories

*See www.econox.com for more information.

4 CarboProbe™ Specification

The CarboProbe™ CP, DS and HT are all based on the C3M ZrO_2 oxygen sensor. They consist of a ZrO_2 oxygen sensor, mounted in an industrial thermocouple head with all electrical and reference air connections. Probes are normally supplied with an internal R-type or S-type thermocouple.
They are suitable for measurement of oxygen concentration at temperatures from 600°C to 1700°C.

- CarboProbe™ HT and DS are accurate enough for research laboratory use. CarboProbe™ DS has a gas tight thread for laboratory use.
- CarboProbe™ HT is robust enough for industrial use and is protected by an alumina ceramic sheath of 15 mm outside diameter, open at the end.
- CarboProbe™ CP is aimed at potters and is not to be used in industrial environment.

Fig 2: CarboProbe™ CP

Fig 3: CarboProbe™ DS

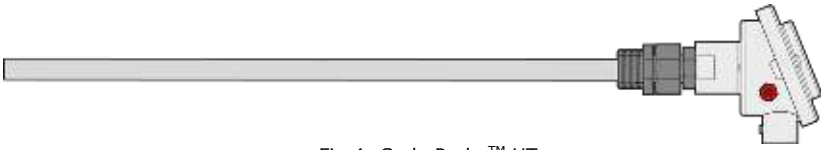


Fig 4: CarboProbe™ HT

	CarboProbe™ CP*	*CarboProbe™* DS*	*CarboProbe™* HT**
Sensor	C3M sensor	C3M sensor	C3M sensor
Head	Grey	Grey	White
Thread	-	M16	¾''
Outer diameter	8.5mm	8.5mm	15mm
Connector	4-pin standard	4-pin standard	4-pin standard
Max length	500mm 19.7''	1100mm 43.3''	1100mm 43.3''
Reference air	1 to 6 l/h	1 to 6 l/h	1 to 6 l/h

* *CarboProbe™* CP shall not be used in an industrial environment
**CarboProbe™* DS is supplied with a gas tight M16 thread
*** *CarboProbe™* HT is a more robust probe with an outer ceramic sheath

Check www.econox.com for more information.

All wiring and electrodes are platinum, for outstanding corrosion resistance and high temperature application. Probes are supplied with a 4-pin electrical connector ready for connection to any suitable 4-conductor cable.

More technical specifications:

Output	0 to 1200 mV
Readout impedance	*CarboProbe*™ should be used with controlling, recording and indicating instruments having input impedance of 10 megaohms or higher
Insertion depth	5 cm minimum
Response time	Less than 1.0 second at 700°C and above
Thermocouples	Type R, S or without
Operating Temperatures	600°C to 1700°C
Mechanical shock	Resists mild mechanical shock; handle carefully
Thermal shock	They should be introduced/removed from furnace slowly (25mm per minute intervals)
Reference air	Uncontaminated dry air at maximum rate of 1 to 6 l/h
Cleaning air	No cleaning air is required

5 Serial number

Econox serial numbers are easy to understand and give you all the details about the characteristic of the probe.

AA-BB-CCC-DDDD-E

AA: Type of Thermocouple

00: No TC
10: S-type
13: R-type

BB: Probe type

10: *CarboProbe™ HT*
11: *CarboProbe™ CP*
15: *CarboProbe™ DS*

CC: Probe length from tip of ZrO_2 sensor to bottom of head

10: 100mm
20: 200mm
30: 300mm
40: 400mm
50: 500mm
60: 600mm
70: 700mm
80: 800mm
90: 900mm
100: 100mm
110: 1100mm

DDDDD: Unique ID number

E: Represent the type of bearing size of probe

3/4: 3/4'' thread

6 Installing the CarboProbe™

Please follow the following recommendations when installing your CarboProbe™.

1. The *CarboProbe™ CP, DS* and HT must be brought up to temperature gradually; otherwise the measuring element and support tube may suffer irreversible damage. In order to avoid this problem, the sensor must be inserted slowly into a furnace that is up to temperature. **The sensor must be inserted or removed gradually over a period of 10 minutes**.

2. Place the *CarboProbe™* where it will not touch the load and will not likely be in struck when loading. The sensor should be inserted so that its tip is approximately **5 centimeters into the kiln/furnace**.

3. If the CarboProbe™ is installed too close to the heating elements or the kiln/furnace door, the temperature cannot be measured correctly. Any difference in temperature between the CarboProbe™ and the thermocouples should be avoided.

4. Thermal and mechanical shocks should be avoided when installing the CarboProbe™ or during the measure (this causes the deterioration of the zirconium oxide measuring element).

5. The temperature of the measuring element must be between 600°C and 1700°C

6. The CarboProbe™ HT is supplied with a 3/4'' connector. The *CarboProbe™* DS with an M16 connector, and the CP with a stainless-steel tube. When fitting them to the kiln/furnace, ensure that the temperature of the probe head does not exceed 80°C.

It is very important that the CarboProbe™ be fitted correctly to your kiln/furnace. The CarboProbe™ HT requires a ¾'' thread while the CarboProbe™ DS requires an M16 thread.

As an alternative, a larger hole can be closed up with ceramic fiber or by simply using a coil of clay. This will prevent back pressure flames from coming out onto the head of the probe and will help to prevent damage.

7. Install the probe anywhere in the kiln or furnace where a thermocouple probe could be installed. If the probe is used at temperatures over 1100°C, the probe should hang vertically, to avoid bends caused by high temperature. The probe will measure the oxygen concentration at the probe tip, provided that the operating temperature is between 600°C and 1700°C.

8. In order to get a representative sample of the atmosphere the *CarboProbe™* should not be placed directly over a burner port or where the gasses move rapidly. Since the *CarboProbe™* is extremely sensitive, the readings may fluctuate rapidly reflecting the non-homogeneous gas environment.

9. Likewise, a corner placement for the sensor is not advised because the gasses might not be well mixed, unless your kiln/furnace has a turbine.

The three best placements are in the **center of the door**, **roof** or **back wall**.

6.1 Electrical connection

Specific cables need to be used for connecting the *CarboProbe™* to the controller. These cables are different depending on the type of thermocouples used in the *CarboProbe™ , and* are called "**compensated cables**." You should always use shielded, compensated cables between the *CarboProbe™* and the controller, up to a maximum length of 30 meters.
Shields should be connected to ground at the instrument end only.

S or R compensated cable OR ordinary copper wire should be used to connect pin 3 and 4 (O_2 signal) to the Controller (**only Pin 1 and 2 cable needs to be compensated**). K compensated cable should not be used to connect the O_2 signal as it will generate a small error that will induce a small variation of $\%O_2$.

Never wire thermocouples using ordinary copper wire.

Econox recommends using the following shielded, compensated cable:

Econox item **008686** - Compensated cable 4 x 0.5 TYPE S, R

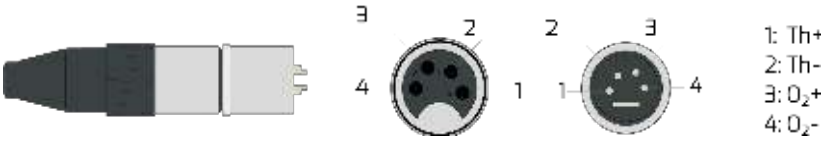


Fig 5: *CarboProbe™* electrical connector

Do not place power wiring and probe wiring in the same conduit. The wires from several oxygen probes may be placed in the same conduit.

The cable should not touch any hot surface of the kiln/furnace.

6.2 Electrical wire color coding

All Econox thermocouple wire are available with IEC 584-3 colors codes.

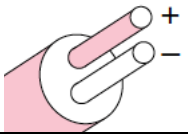
K		–270 to 1372°C –454 to 2501°F
S		–50 to 1768°C –58 to 3214°
R		–50 to 1768°C –58 to 3214°
N		–270 to 1300°C –450 to 2372°F
O_2	Econox standard for O_2 signal is BLUE for (+) and BLACK for (–)	

Fig 6: *Wire color coding*

6.3 Working with an O_2 probe (oxidation/reduction)

Working with an oxygen probe is easy if you understand the value it gives. When it comes to oxidation or reduction, roughly speaking, a reading less than 100mV represents oxidizing conditions and a reading over 300mV represents reduction. Heavy reduction might give a reading of 500mV or even more. In between 100mV and 300mV the temperature must be known for accurate interpretation.

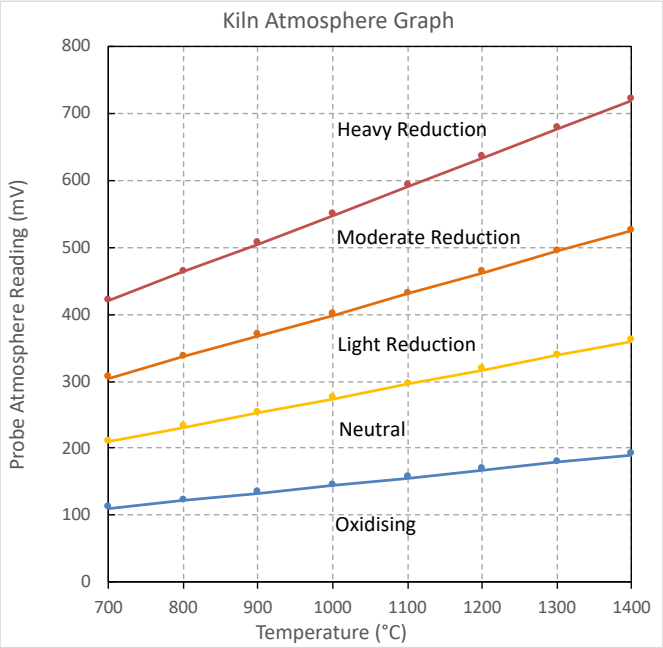


Fig 7: *Kiln atmosphere graph (mV vs temp)*

In any flame, the air and fuel never mix perfectly. As burning fuel blows past the tip of the oxygen probe, some of the flame will have excess air and some will be gas rich. This means that the oxygen reading will jump around as the flame flickers past. This is most noticeable when there is just the right amount of air to give a neutral flame.

Air consists of 20.9% oxygen, about 78% nitrogen and some trace gases. In a flame, the fuel combines with the oxygen in the air and burns, forming carbon dioxide and water vapor (steam). Inside a kiln, there is a mixture of fuel, oxygen, carbon dioxide, steam and nitrogen. The amount of each of these depends on the amount of fuel and air in the flame.

6.3.1 Oxidizing flame*

With excess air, there is typically over 2% oxygen in the exhaust gas, but it can be almost up to the limit of 20.9%. This is called an "oxidizing" flame.

6.3.2 Neutral flame*

With exactly the right amount of air for the fuel, there is a "neutral" flame. Even in ideal conditions, there will be some fuel and some air that cannot find each other to burn completely. A little unused fuel and air will be in the exhaust gas leaving the kiln. There is typically anything from 0.02% to 2% unused oxygen in the exhaust.

6.3.3 Reducing flame*

With too little air, there will be unburnt fuel in the exhaust gas. This is called a "reducing" flame. Many people say that there is no oxygen under these conditions, but there will always be some unused oxygen in the exhaust. It might be less than 0.02%. The oxygen present might be less than 0.000001%, but it can be measured.

*There is no sharp distinction between oxidizing, neutral and reducing. There is a smooth variation from one to the next, so the above figures are only guidelines.

6.4 Calculating the O_2 concentration

The table below shows the relation between the mV from the probe and the temperature, used to calculate the $\%O_2$.

°C mV	800	900	1000	1100	1200	1300	1400
25	7.1	7.8	8.4	9.0	9.5	10.0	10.4
50	2.4	2.9	3.4	3.9	4.3	4.8	5.2
75	0.8	1.1	1.4	1.7	2.0	2.3	2.6
100	0.26	0.40	0.55	0.71	0.89	1.09	1.30
125	0.09	0.15	0.22	0.31	0.41	0.52	0.65
150	0.03	0.06	0.09	0.13	0.18	0.25	0.33
175	0.01	0.02	0.04	0.06	0.08	0.12	0.16
200	0.004	0.008	0.014	0.024	0.038	0.057	0.081
225	0.001	0.003	0.006	0.010	0.017	0.027	0.041
250	0.000	0.001	0.002	0.004	0.008	0.013	0.020
275	0.00014	0.00039	0.00092	0.00192	0.00360	0.00625	0.01015
300	0.00005	0.00015	0.00037	0.00082	0.00164	0.00299	0.00507
325	0.000016	0.000054	0.000148	0.000353	0.000745	0.001428	0.002534
350	0.000006	0.000020	0.000060	0.000152	0.000339	0.000683	0.001266
375	0.0000019	0.0000075	0.0000241	0.0000651	0.0001541	0.0003266	0.0006327
400	0.00000063771	0.00000278827	0.00000966903	0.00002797462	0.00007006485	0.00015614683	0.00031620647

Fig 8: Example of calculated value in $\%O_2$

6.4.1 Manual calculation

If you wish to do your own manual O_2 calculation you can download our Excel file from www.econox.com/documentation . This file allows you to input the temperature as well as the mV coming from the probe and returns a calculated value of the O_2 in %, ppm, and log.

6.4.2 Automatic calculation

Automatic management of the CarboProbe™ including automatic O_2 calculation can be achieved using our ControX box.

ControX includes an O_2 calculator and display, temperature display, data recording and USB export, 4-20 mA output (for O_2 and temperature), as well as a pump to supply a constant flow of reference air to the probe!

More information can be found on www.econox.com.

6.5 Special note for Potters

The CarboProbe™ CP is able to identify precise combustion atmospherics no matter what the weather conditions are. For instance, when the weather is clear, and the barometer indicates high pressure, there is more oxygen available to the burners.

If you set the available air to the same physical setting each time, you may be varying the oxygen/fuel ratio by 15% or more relative to the air available when it is stormy, and the barometric pressure is low.

Many potters note that they get "better reduction" in stormy weather. What actually is happening is they are simply using the same settings for their burners and getting less oxygen.

With our CarboProbe™ CP you adjust the burners to the atmospheric indication according to the mV coming from the CarboProbe™.

Noting the time of the firing, plot the atmospheric reading and the temperature. Each firing should be charted, and adjustments noted. At some point your particular glazes will fire efficiently and beautifully.

Once you have the readings charted (and no matter what the weather conditions are) you can repeat the results.

As a potter, here are your advantages:

Fuel savings - an economical firing depends on supplying the right ratio air/fuel, without waste of energy from heating excess air.

Reliable glaze colors - Knowing the right level of reduction every firing gives you the colors you want, firing after firing.

Reduced air pollution - Use the CP Probe as a guide for stoking wood-fired kilns to reduce wood consumption and unnecessary ash and smoke.

7 Probe operation and maintenance

The Econox *CarboProbe™* requires no mechanical maintenance and any attempt to dismantle it within the warranty period (see warranty card) will invalidate the warranty. The integrity of any atmosphere control system depends on the sensor/measurement device. It is no different for oxygen probes, as the probe is most often in situ and subject to many different types of factors.

CarboProbe™ need an adequate flow of reference air to work (see chapter 7.1). No purging/cleaning air is available on these Probes.

7.1 Reference air

A constant flow of Reference Air 1 to 6l/h is needed to maintain the accuracy of the *CarboProbe™*.

Reference air should be **dry**, **clean** and **free** from any contamination.

Compressed air should not be used. Econox can provide a probe air supply cabinet, which provides separate air pumps for reference air and probe cleaning air.

CHECK AND ADJUST reference air flow as necessary at least ONCE PER DAY

Please note the following color-coded reference air inlet.

Reference air

Fig 9: CarboProbe™ CP, DS and HT color coded air inlet
(RED= HT; BROWN = CP and DS)

7.2 Inserting-removing from kiln/furnace

The *CarboProbe™ CP, DS* and HT must be brought up to temperature gradually; otherwise the measuring element and support tube may suffer irreversible damage. In order to avoid this problem, the sensor must be inserted slowly into a furnace that is up to temperature.

As a precaution introduce (or remove) the CarboProbe CP, DS amnd HT into a hot furnace in stages of 25mm per minute intervals.

8 Troubleshooting

8.1 Introduction

Unfortunately, there is no definitive method for determining the accuracy of an oxygen probe. The only way to establish that the *CarboProbe™* is reading accurately is to compare the reading with a reference oxygen probe or a gas analyzer.

When there are doubts as to the validity of *CarboProbe™* readings, a few simple tests conducted while the *CarboProbe™* is in operation can assist in diagnosing the problem.

8.2 Probe location

If your probe is placed near or directly above your burner, you may experience significant fluctuation on your readings. This is not due to a probe problem but rather it accurately reflects how the atmosphere is rapidly changing in some areas of the kiln. It is best to place the probe in other parts of the kiln.

8.3 Checking the impedance of the sensor

The output impedance of an oxygen probe is a function of the electrode contact area, materials of construction, and temperature. The lower the impedance, the more surface area is in contact with the electrode assembly. A value below 25K ohms at temperature above 800°C is acceptable; once the value rises above 50K ohms it is necessary to change the probe.
Some controllers have built-in probe impedance testing.

8.4 Checking the reference air and air tightness

Prior to anything else, disconnect the reference air supply from the head of the *CarboProbe™* and check that air is indeed flowing into it. Reconnect the reference air. Check whether the air supply tube is connected to the red connector. Then perform the following procedures:

While the *CarboProbe™ CP, DS or HT* is in operation, suddenly cut the reference air supply (by pinching the tube with your fingers). The output signal from the *CarboProbe™* should not drop by more than a few mV in one minute.

After releasing the tube, the voltage displayed should immediately return to its initial value. If the change was greater than 25 mV, the *CarboProbe™* sensor is probably cracked and is therefore giving incorrect readings, in which case it must be repaired.

8.5 Checking the thermocouple

If your *CarboProbe™* has a thermocouple inside, disconnect the connection cable and use a voltmeter to check the output signal***** from the thermocouple.

Start at the controller and gradually work back to the *CarboProbe™* terminals, then towards the thermocouple wires inside the *CarboProbe™* head. Take a number of readings along the way to pinpoint the defect.

ECONOX can, upon request, provide millivolt-temperature conversion tables for S-, R- and K-type thermocouples.

*Check www.econox.com/documentation for more information

8.6 Checking the oxygen signal

If the *CarboProbe™* gives an oxygen signal but the signal seems to be incorrect, perform the following checks. All of these may be performed while the *CarboProbe™* is in the furnace. They do not constitute any kind of calibration, but they do give an indication of the condition of the sensor.

1. Measure the oxygen mV signal. Leave the voltmeter connected to the terminals and **(20 sec maximum)** short-circuit the oxygen mV pins on the sensor; then remove the short-circuit. The mV signal should return immediately to initial value(<30s). If the signal slowly returns (>3 min.), it means that the *CarboProbe™* is defective and should be replaced.

2. Now disconnect the connection cable and use a voltmeter to check the mV signal. Start at the controller and gradually work back to the *CarboProbe™* terminals. Take a number of readings along the way to pinpoint the defect. If the defect lays within the *CarboProbe™* itself, it must be repaired.

9 Factory service

The Econox *CarboProbe™* is a highly technical measuring instrument subject to potentially difficult working conditions. The lifetime of the *CarboProbe™* depends, to a large extent, on the conditions in which it is used. If you suspect that the *CarboProbe™* is malfunctioning, and the troubleshooting section (chapter 8) has not helped you in solving the problem encountered, then it probably requires repair.

When sending a *CarboProbe™* for repair, pack it carefully in its original packaging, mark it "**Fragile Instrument**" and send it back to us.

If you are shipping from outside of Switzerland please enclose a pro-forma invoice (http://www.econox.com/send-defective-probe) with a maximum value of 300 euros per unit.

Then return it to:

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2942 Alle – Switzerland

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